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Individually controlled localized chilled beam in conjunction with chilled ceiling: Part 1 – Physical environment

Taha Arghand[1,2], Zhecho Bolashikov[1], Risto Kosonen[3] and Ilari Aho[4], Arsen Melikov[1]

[1]International Centre for Indoor Environment and Energy, Department of Civil Engineering, Technical University of Denmark, Kgs. Lyngby, Denmark
[2]Department of Building, Energy and Environmental Engineering, University of Gävle, Sweden
[3]Halton OY, Finland
[4]Uponor Group, Finland

[*]*Corresponding author email: taha.arghand@gmail.com*

SUMMARY

This study investigates the indoor environment generated by localized chilled beam coupled with chilled ceiling (LCBCC) and compares it with the environment generated by mixing ventilation coupled with chilled ceiling (CCMV). The experiments were performed in a mock-up of single office (4.1 m × 4.0 m × 3.1 m, L× W× H). Thermal manikin was used to simulate room occupant. The LCBCC was placed above the workstation to improve the environment locally. Combinations of indoor temperature of 26 °C and 28 °C and ventilation airflow rate of 10 and 13 l/s were studied. The total heat load in the room was 60 W/m^2 (including simulation of solar radiation and miscellaneous heat loads). The results showed that uniform thermal conditions (differences smaller than 1 °K) were generated in the occupied zone with the studied system configurations. The LCBCC diminished the effect of the buoyancy flow from the simulated window and this resulted in more acceptable thermal conditions at the workstation.

PRACTICAL IMPLICATIONS: From the energy saving prospective in commercial buildings, creating local environment where occupants spend most of their active time has little been studied. This study provides information for generated indoor environment by localized chilled beam combined with chilled ceiling.

KEYWORDS: Localized chilled beam, Mixing Ventilation, Chilled ceiling, Individual control, Local environment.

INTRODUCTION

The main purpose of applying air-conditioning system is to provide/extract heat to/from a room. The primary purpose of using ventilation system is to supply clean air and remove the polluted air and thus to reduce contaminants in the room. In some air conditioning systems these functions are combined. Total volume ventilation is the most widely used method for ventilation, cooling and heating in buildings. Despite the fact that uniform indoor condition and low gradients are desirable in rooms, total volume ventilation have some potential problems: complicated interaction between supply air and internal heat sources which makes the supply jet difficult to control, long distance between the supply diffuser and the occupants which causes the supplied clean and cool air to mix with warm and polluted room air by the time it reaches the occupant, low possibility for satisfying a majority of occupants due to the individual differences, etc. (Melikov, 2011).

Personalized ventilation is an efficient method to produce local environment for each occupant (Melikov, 2004). Non-uniform environment under individual control of occupant can be generated by modifications of the used at present methods for air distribution. Active chilled beams are widely used today. They can be used as localized chilled beams (LCB) to establish local environment at workstations under individual control for every occupant (Uth et al., 2014). However, the use of the LCB alone leads to non-uniform environment with high temperature in the occupied zone, which could cause thermal discomfort to the occupants when they have to move out of the workstation (Uth et al., 2014). One possibility to improve the thermal environment outside the local environment generated at the workstation with the LCB is to combine it with chilled ceiling and make use of the provided radiant cooling.

The present study investigates the performance of Localized Chilled Beam combined with Chilled Ceiling (LCBCC) with regards to the generated indoor environment. The performance of the LCBCC was compared with the performance of chilled ceiling combined with mixing ventilation (CCMV).

METHOD

Experimental set-up

The measurements were carried out in an environmental chamber 4.1 m × 4.0 m × 3.1 m (L× W× H) with two workstations to simulate an office room, Figure 1. The direct sunlight radiation was simulated by electric heating foils (2.0 m × 4.0 m) placed on the floor and radiative water panels with total area of 6.24 m^2 simulating window surface on one of the walls. Other heat sources in the room were lighting (140 W), one laptop at each workstation (90 W totals) and a thermal manikin (65 W/m^2). The summer condition with total heat load of 60 W/m^2 was simulated.

Two systems, namely Localized Chilled Beam combined with Chilled Ceiling (LCBCC) and Chilled Ceiling combined with Mixing Ventilation (CCMV) were studied. The chilled ceiling had 18 radiant panels which covered about 75% of the ceiling area. The mixing ventilation (MV) consisted of two ceiling-mounted linear diffusers (0.1 m × 0.52 m). The used chilled beam (CB) in the study was an active chilled beam (1.20 m × 0.60 m). The CB was modified by installing "wing-like" structures which directed the supplied flow so that local environment with elevated velocity was generated at one of the workstations, WS1 (located near the simulated window), where the CB was installed. It was possible to control the airflow rate supplied from the CB via a voltage controlled damper connected to a potentiometer. The knob of the potentiometer was placed on the table under the CB, WS1. The second workstation, WS2, was placed near the wall opposite to the simulated window as shown in Figure 1. It was used to evaluate the room thermal environment away from WS1.

Flow pattern measurements

Mean air velocity, temperature and turbulence intensity were measured by low velocity thermal anemometer with eight low velocity omni-directional wireless transducers (SENSOR 5100SF). The measurements were performed at eight heights (0.05, 0.1, 0.3, 0.6, 1.1, 1.4, 1.7 and 2.0 m from floor) and at 18 points grid within the simulated office and at the two workstations. Measurements of air temperature (t_a) and air velocities were also carried out at two reference points, i.e. near the two workstations. The mean air velocity was measured with an accuracy of 0.03 m/s ±1% in the range of 0.05-5 m/s.

Operative temperature (t_o) measurements were performed at four heights (0.1, 0.6, 1.1, and 1.7 m) above the floor by means of a gray globe sensor (diameter of 4 cm). The measurements at each point lasted 300 s. The measurements of air and operative temperatures and air velocity were performed with the presence of the manikin at WS1.

Experimental conditions

The performance of the LCBCC and CCMV was studied at two room air temperatures - 26 and 28 °C. The test conditions and operation parameters are listed in

Table **1**. The maximum flow rate used (13 L/s) corresponds to Category II for very low-polluting building with one occupant, EN 15251 (2007). The minimum flow rate (10 L/s) was also according to Category III, EN 15251 (2007) for very low polluting building. The room air temperature was set at 26 °C (EN 15251 (2007)Category II), i.e. cooling case (during summer).

Throughout the paper each case study is identified as an acronym consisted of the applied system (LCBCC or CCMV), room air temperature (26 or 28 °C) and the supply flow rate (10 or 13 L/s), respectively. For instance, LCBCC26-10 stands for a case with LCBCC system at 26 °C with 10 L/s primary flow for the CB.

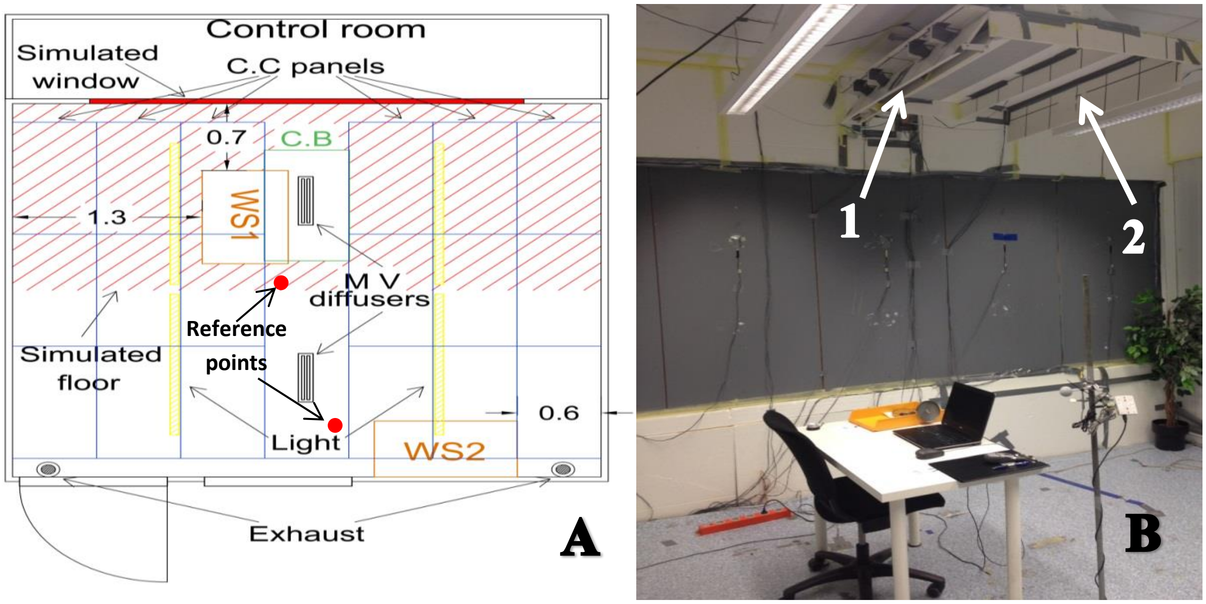

Figure 1. A) The room layout with tested systems, and B) Position of the radiant window and the CB to WS1

Table 1. Average (standard deviation) operation parameters of six test conditions

Condition		LCBCC 26-10	LCBCC 26-13	LCBCC 28-10	LCBCC 28-13	CCMV 26-13	CCMV 28-13
Supply air temperature (°C)		15.4 (±0.0)	14.8 (±0.1)	15.5 (±0.0)	14.9 (±0.0)	14.7 (±0.4)	15.3(±0.1)
CB water temperature (°C)	Supply	21.2 (±0.0)	21.2 (±0.0)	21.3 (±0.0)	21.3 (±0.0)	-	-
	Return	22.3 (±0.0)	22.5 (±0.0)	22.9 (±0.0)	23.1 (±0.0)	-	-
CC water temperature (°C)	Supply	17.1 (±0.1)	17.2 (±0.0)	21.6 (±0.1)	21.4 (±0.1)	15.9 (±0.0)	20.7 (±0.0)
	Return	18.3 (±0.1)	18.3 (±0.0)	22.5 (±0.1)	22.3 (±0.1)	17.2 (±0.0)	21.7 (±0.0)
Airflow rate (L/s)		10.2 (±0.1)	13.1 (±0.1)	10.1 (±0.1)	13.2 (±0.1)	12.9 (±0.3)	12.8 (±0.2)

RESULTS

Thermal environment in the room

Previous human subject study (Uth et al., 2014) indicated that the use of LCB without CC resulted in unacceptable thermal comfort outside of the local environment at the WS1. Therefore one of the important goals of this study was to achieve acceptable thermal conditions not only at the WS1 with the LCB but also in the rest of the occupied zone. Because of this the LCB was used together with the CC. The comparison of the operative temperature (t_o) measured with LCBCC and CCMV under similar room temperature revealed the positive function of the CC system for providing equal thermal condition outside of the WS1, including at WS2.

Operative and air temperatures, (t_o and t_a) within the occupied zone outside of the workstations was uniformly distributed with horizontal and vertical gradients less of than 1.2 °K, Table 2. Due to the presence of warm window on the left side of the room, the difference between (t_a) and (t_o) close to the window was distinguished. Conversely, on the other side of the room, further away from the simulated wall and floor, the magnitude of the difference between (t_a) and (t_o) decreased. Nevertheless, lower (t_a) than (t_o) indicates that the impact of the simulated wall and floor was not totally diminished. Air velocity field was relatively uniform in the occupied zone outside of the workstations.

Table 2. Average air and operative temperature within the occupied zone at 0.6 m above the floor

Experiment condition		LCBCC 26-10	LCBCC 26-13	LCBCC 28-10	LCBCC 28-13	CCMV 26-13	CCMV 28-13
t_a (°C)	Avg (SD)	26.1 (±0.3)	26.3 (±0.3)	28.3 (±0.3)	28.1 (±0.3)	25.9 (±0.2)	28.0 (±0.2)
	Max	26.5	26.8	28.7	28.4	26.3	28.4
	Min	25.3	25.7	27.5	27.0	25.5	27.4
t_o (°C)	Avg (SD)	26.2 (±0.3)	26.5 (±0.4)	28.5 (±0.4)	28.3 (±0.4)	25.9 (±0.4)	28.0 (±0.4)
	Max	26.9	27.3	29.3	28.9	26.6	28.8
	Min	25.8	26.1	28.1	27.7	25.4	27.4

Thermal environment at workstations

Vertical temperature distribution at the Ref.P.1 at WS1 with LCBCC and CCMV systems at 26 °C and 28 °C room temperature are shown in Figure 2. The air temperature of the flow supplied from the LCB at WS1 did not differ much than the average temperature in the occupied zone. The reason could be the mixing of the supplied flow with the warm plumes generated by the seated occupant and the simulated warm window. Fluctuations in air temperature profile are not large, so that the temperature difference between the lowest and highest measured locations within the occupied region at WS1, i.e. between 0.1 m and 1.7 m, is less than 1 °K.

Vertical velocity air temperature profiles for LCBCC-10 L/s at 26 °C and 28 °C are shown in Figure 2. The ability of LCBCC in generating the highest air velocity with the maximum and minimum airflow rates at 1.1 m which corresponds to the head of the seated occupant can be seen in Figure 2. However it may be expected that these relatively high velocities will not cause draught for the occupant seated at WS1. As documented by other studies (Melikov, 1994, 2004; Melikov et al., 2003; Sekhar et al., 2005), the appropriate facial air movement has positive effect on improving thermal conditions for the occupant. Based on EN15251 (2007) the elevated air speed can diminish the effect of high room air temperature to some degree if it exceeds 26 ^{o}C. This facial air movement could bring refreshing feeling for the occupant. Elevated facial movement will also improve the perceived air quality (Melikov and Kaczmarczyk, 2012). Performed human subjective experiments showed that subjects accepted the elevated velocities at this height, (Arghand et al., 2016).

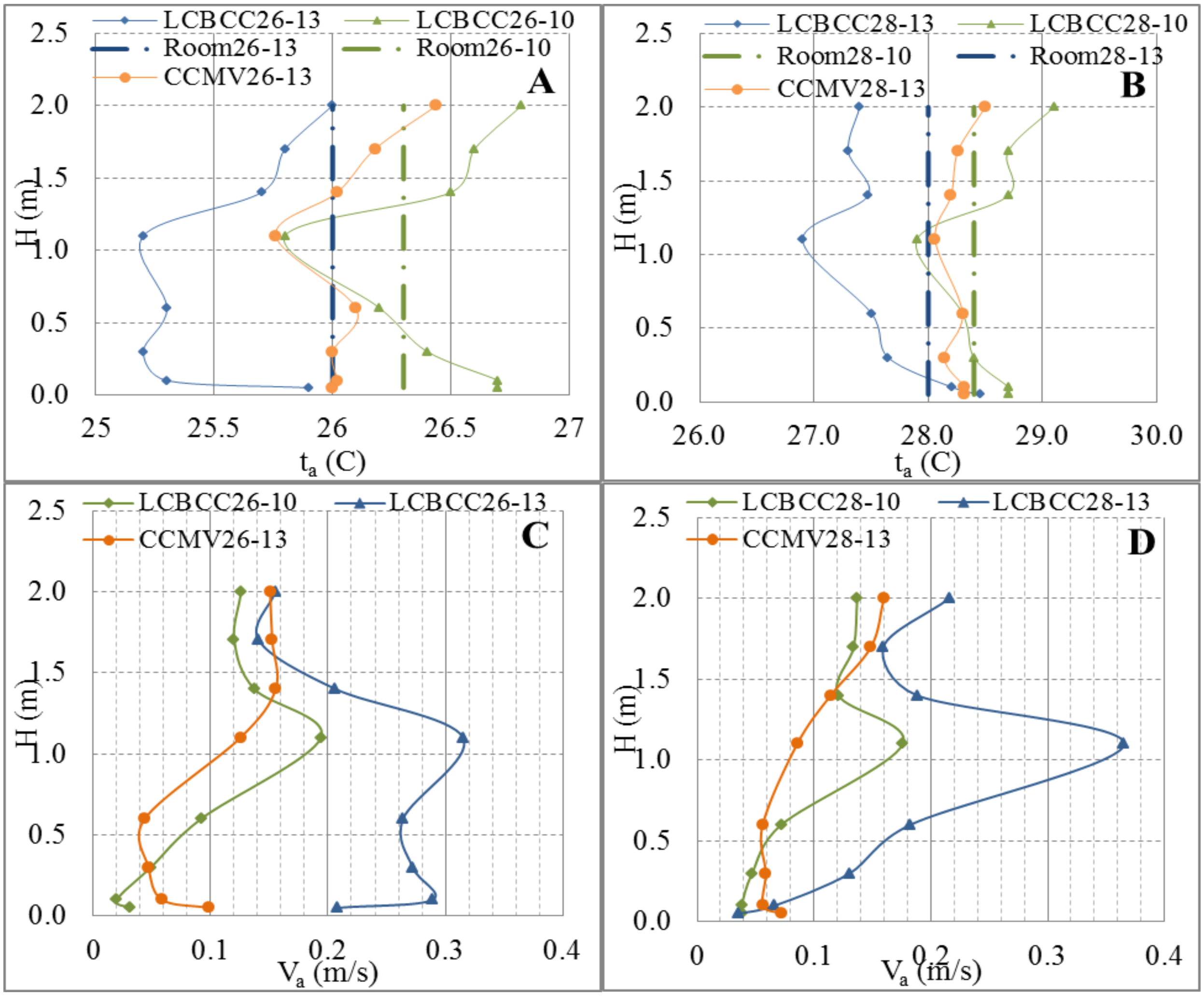

Figure 2. A, B) Vertical temperature gradient, and C,D) vertical velocity gradient at WS1 under test conditions

It was identified that the air temperature and air velocity fluctuations at WS2 were small under the studied air temperatures and airflow conditions. This result suggests that changing the airflow rate does not have considerable effect on the thermal condition at WS2, Figure 3. However the thermal condition at WS2 was affected by the air flow pattern in the room under the CCMV system. Fairly high air velocity especially at the upper part of WS2 was measured, Figure 3.

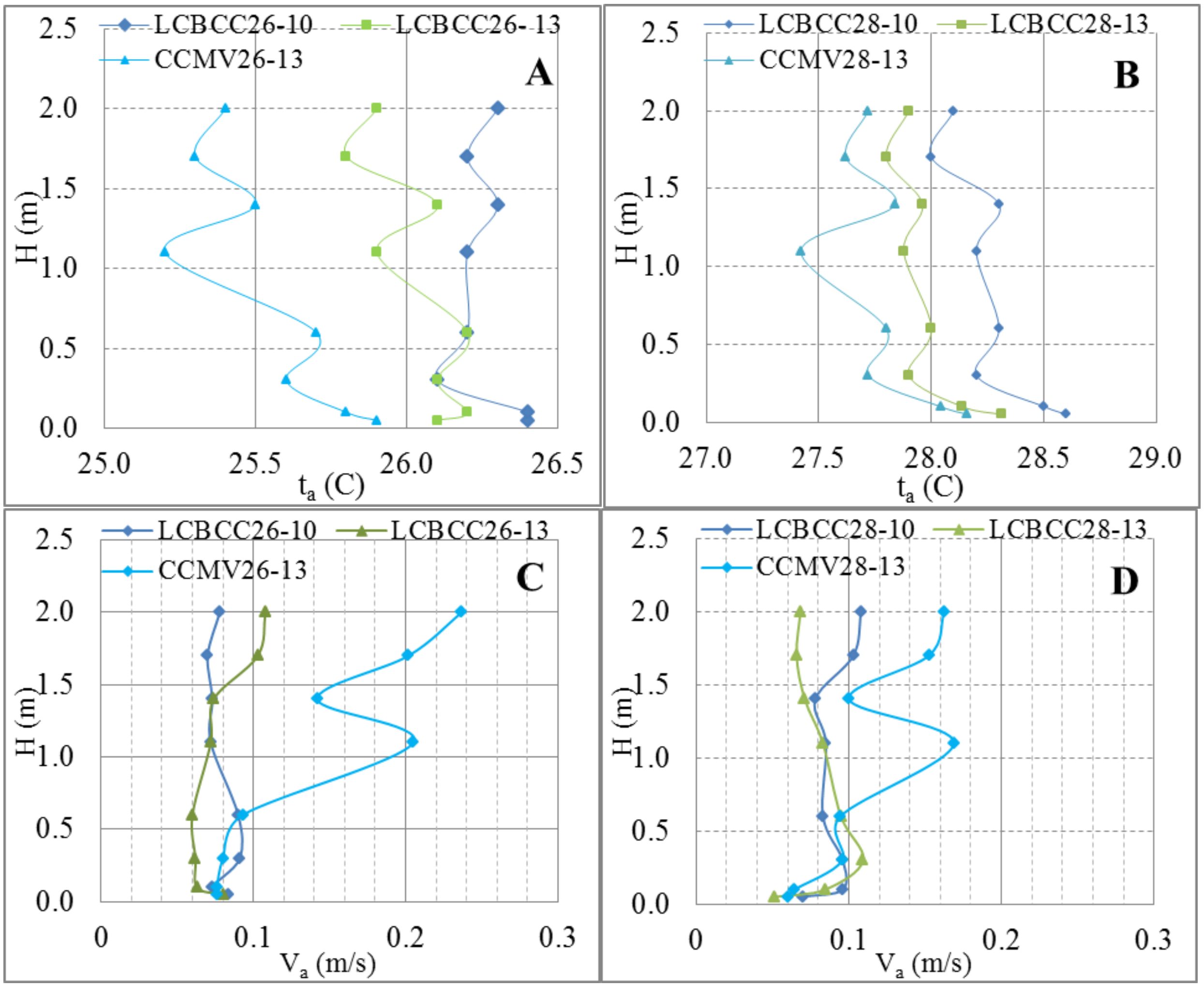

Figure 3. A, B) Vertical temperature gradient, and C,D) vertical velocity gradient at WS2 under test conditions

CONCLUSIONS

The following conclusions can be made based on the findings:

- The significant advantage of applying LCB for the occupant would be the facial air movement which can be controlled to some extent by the adjusting the airflow rate. The airflow pattern established at the WS1 was more robust with LCBCC compared to CCMV. The supplied airflow was less affected by convective plume generated by the heat sources in cases with LCBCC.
- The LCBCC system created the same thermal condition as the CCMV at the WS1 with less airflow rate. This can be regarded as a major benefit of the LCBCC system over the CCMV system from the energy saving point of view.

- Air and operative temperature distribution in the occupied zone with LCBCC and CCMV was almost uniform with no difference higher than 1.2 K between the measured locations in the room. The chilled ceiling diminished the effect of the buoyancy flow from the simulated warm window and warm floor resulting in better distribution of the flow in the room and less discomfort due to radiant temperature asymmetry at WS1.

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